

1 **Amendment to the Specification**

2 **In the Specification:**

3 Please amend the specification as follows:

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6 On page 1, line 3 after the title, please add the following section heading and paragraph:

7
8 **Related Applications**

9 This application is a continuation-in-part (CIP) of a patent application, Serial No. 09/496,999,
10 filed on February 3, 2000, which was co-pending at the time this application was filed and is now
11 issued as U.S. Patent No. 6,537,506, the benefit of the filing date of which is hereby claimed
12 under 35 U.S.C. § 120.
13

14
15
16 On Page 25, before the paragraph and heading beginning at line 29, please add the following
17 new paragraphs (this addition represents disclosure being imported from the parent application in
18 which priority is claimed, as noted above, and does not represent new matter).
19

20 Another aspect of the present invention is a microreactor for use in the modular reaction
21 system, for reacting one chemical with at least one other chemical, for the purpose of forming a
22 chemical product. The reactor includes a plurality of simple plates, each simple plate having at least
23 one opening formed therein, the simple plates being stacked together to form a plurality of layers and
24 arranges so that at least one opening in each simple plate overlaps at least one other opening in an
25 adjacent simple plate, thereby forming at least one pathway between at least some of the layers.
26

27 Preferably, openings within different layers align so as to form at least one inlet port and at
28 least one outlet port, for the receipt and discharge of chemicals, and to form at least one pathway for
29 conveying chemicals to be processed. At least one pathway is formed that is in fluid connection with
30 the inlet and outlet ports, and each simple plate has at least one opening formed in it.

1 A material from which the simple plates are fabricated is selected for compatibility with the
2 chemical process. In one embodiment, the simple plates are formed from a material selected from the
3 group consisting of crystalline wafers, ceramics, glasses, polymers, composite materials, and metals.
4 Preferably, if formed from a metal, stainless steel is used. The material of the crystalline wafer is
5 selected from the group consisting of silicon and germanium.

6 It is also preferable that the reactor accommodate a plurality of operations, including
7 temperature control, control of chemical residence time, chemical mixing, and chemical reacting.
8 Temperature control is achieved using a combination of one or more temperature sensors and one or
9 more heat exchangers. Preferably, chemical mixing is carried out by employing pathways sized so
10 that a reactant achieves a stacked laminar flow with respect to at least one other reactant.

11 In a reactor adapted for processing at least two reactants to form a desired chemical product,
12 an inlet opening for each of the reactants and an outlet opening for the chemical product is provided
13 in at least one of two outer simple plates. An intermediate simple plate is included for mixing the
14 reactants and has at least one opening in fluid communication with each inlet opening and the outlet
15 opening.

16 Generally, at least one heat transfer fluid inlet port is included in at least one of the outer
17 simple plates, so that at least one heat transfer fluid can be introduced into the chemical reactor. Each
18 heat exchanger is defined by an opening in a different intermediate simple plate. The opening is in
19 fluid communication with the heat transfer fluid inlet and outlet ports and is disposed between
20 adjacent simple plates.

21 Preferably, each heat exchanger is used to modify the temperature of at least one of the
22 reactants and/or the chemical product. The heat exchangers can be used to modify a temperature of
23 one of two reactants such that they are at different temperatures.

24 The thickness of the outer simple plates is about 3 millimeters, and that of the plurality of
25 intermediate simple plates is at least about 0.2 millimeters, but not more than about 0.6 millimeters.

26 Preferably, when the thickness of the intermediate simple plates that are adjacent to a heat
27 exchanger is about 0.3 millimeters. When a series of openings in the simple plates of the chemical
28 reactor defines a fluid path for a heat transfer fluid that flow through more than one heat exchanger,
29 the flow rate and fluid pressure of the heat transfer fluid within each such heat exchanger are
30 substantially.

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4 On Page 8, please amend the paragraph beginning on line 30 as follows:
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6 FIGURE 15 is a simplified process flow diagram for a preferred embodiment of a modular
7 microreactor system that utilizes a serial heat transfer media fluidic system in accord with the present
8 invention[.]; and
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12 On Page 8, immediately after the paragraph beginning on line 30 and ending on line 33
13 (amended as noted above), please add the following new paragraphs (note that this addition
14 represents disclosure being imported from the parent application, and does not represent new matter).
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16 FIGURE 16 is an exploded isometric view of an exemplary reactor, illustrating how sixteen
17 simple plates are stacked to achieve the exemplary reactor;

18 FIGURE 17A is an exploded isometric view of the first six simple plates of the exemplary
19 reactor, illustrating a fluid path for a first reactant;

20 FIGURE 17B is an exploded isometric view of the first six simple plates of the exemplary
21 reactor, illustrating a fluid path of a second reactant;

22 FIGURE 17C is an exploded isometric view of simple plates seven through sixteen of the
23 exemplary reactor, illustrating the combined fluid paths of the first and second reactants after they
24 have been mixed, and then through the balance of the exemplary reactor;

25 FIGURE 18A is an exploded isometric view of the first two simple plates of the exemplary
26 reactor, illustrating a fluid path for heat transfer media servicing the first heat exchanger;

27 FIGURE 18B is an exploded isometric view of the first four simple plates of the exemplary
28 reactor, illustrating a fluid path for heat transfer media servicing the second heat exchanger; and
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1 FIGURE 18C is an exploded isometric view of the first thirteen simple plates of the
2 exemplary reactor, illustrating the fluid paths for heat transfer media servicing heat exchangers three
3 and four.
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6 On Page 25, before the paragraph beginning at line 5, please add the following new section
7 heading and paragraphs (this addition represents disclosure being imported from the parent
8 application, and does not represent new matter).
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10 An Exemplary Stacked Plate Microreactor
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12 As noted above, particularly preferred embodiments of the present invention will implement a
13 stacked plate microreactor. The following disclosure, originally provided in the commonly assigned
14 co-pending parent application (U.S. Patent Application, U.S. Serial No. 09/496,999, entitled
15 "MINIATURIZED REACTION APPARATUS," which was filed February 3, 2000), describes a reactor
16 for reacting one chemical with at least one other chemical, for the purpose of forming a chemical
17 product. The reactor includes a plurality of simple plates, each simple plate having at least one
18 opening formed therein, the simple plates being stacked together to form a plurality of layers and
19 arranged so that at least one opening in each simple plate overlaps at least one other opening in an
20 adjacent simple plate, thereby forming at least one pathway between at least some of the layers.

21 Unlike prior art stacked layer chemical reactors that require relatively complicated surface
22 features, such as grooves or channels that do not penetrate the component to be formed into each
23 layer, the simple plates employed in the present invention require no more than an opening be formed
24 through each plate. Machining or stamping openings into a flat plate is significantly less complicated
25 than the silicon etching, injection molding, and ceramic molding/sintering processes described in the
26 prior art for producing the surface features that the prior art uses to channel fluid flow. Yet the
27 relatively simple technique of forming openings in a flat plate can be used to achieve a very useful
28 chemical reactor, if the openings are properly placed, and the plates are properly configured and
29 stacked so that the openings in the plates cooperate to convey fluids through the apparatus.
30

 In the following description and the claims that follow, it will be understood that the term
"simple plate" means a plate that has substantially planar opposed surfaces, e.g., a flat sheet of

1 material. In an exemplary reactor, no openings penetrate the peripheral edges defining the perimeter
2 of the simple plates ,and fluid passages used to implement heat exchangers are not in fluid
3 communication with fluid passages for reactants or products, or fluid passages corresponding to
4 reaction volumes and mixing volumes. The simple plates used in the embodiments of the present
5 invention disclosed herein are all generally rectangular and are characterized by having one or more
6 openings that pass completely through the simple plate. Thus, the term "simple plate" as used herein
7 and in the claims should be understood to mean a plate that does not include any etchings, grooves, or
8 channels that do not completely penetrate the plate.

9 The term "groove," as used herein, should be understood to mean a surface feature that has
10 been formed into the surface of an object that does not penetrate completely through the object, and
11 applies to components of prior art chemical reactors.

12 The plurality of stacked simple plates enables a reactor to be constructed that performs from
13 one to all of the following functions: reactant conditioning, control of reactant supply, thermal
14 pre-treatment, combination and mixing of reactants under controlled thermal conditions, intermediate
15 thermal treatment, post-procedural isothermal containment, post-procedural thermal treatment of
16 reactant products, and product separation. In particular, simple plates can readily be designed and
17 fabricated in which the dimensional characteristics of the reactant fluid passages formed by the
18 interconnected openings of the simple plates provide for a stacked laminar flow of the reactants.
19 Such a stacked laminar flow ensures that a particularly efficient type of mixing, referred to as
20 diffusion mixing, can occur.

21 The fluidic system of the stacked simple plate reactor is preferably characterized by having a
22 small pressure drop across the entire system. Furthermore, potential clogging problems are
23 minimized by having few constrictions within the reactor, by introducing as few sharp directional
24 flow changes as possible, by maintaining a small inner volume (about 1 ml), and by enabling rapid
25 diffusion mixing in the mixing portion of the reactor. Preferably, fluidic channel geometries range
26 from 100-500 μm , especially with respect to reactant fluid pathways (the dimensions of any heat
27 transfer media pathways are less critical), and the walls separating the heat transfer media from the
28 reactants or product should be of similar scale, to enable rapid heat transfer. As discussed above,
29 several materials can be used to fabricate a stacked simple plate reactor; however, simple plates that
30 are adjacent to openings in those simple plates comprising heat exchangers are preferably fabricated

1 from a material that has good thermal conductivity. However, if the dimensional thickness of each
2 plate adjacent to a heat exchanger is small, on the order of 0.3 mm, the effect of the thermal
3 conductivity of different materials is negligible.

4 In general, the openings in each simple plate of a stacked simple plate reactor correspond to a
5 fluid pathway established by stacking a plurality of simple plates, such that openings in simple plates
6 above and below overlap, thereby allowing fluids to move throughout the reactor. Openings may
7 also correspond to passageways for sensors, particularly temperature sensors. Preferably, to
8 maximize heat transfer, the fluid flow directions of the heat transfer media within openings defining a
9 heat exchanger are opposite to the direction of reactant flow.

10 FIGURE 17 is an exploded isometric view of a preferred reactor 100 that includes the sixteen
11 layers. Simple plates 110-260 are shown stacked in order so that the relative positions of each simple
12 plate to each other may be examined. The preferred dimensional thickness of each simple plate is as
13 follows:

14	Top simple plate 110:	3.0 mm.
15	Second simple plate 120:	0.3 mm.
16	Third simple plate 130:	0.3 mm.
17	Fourth simple plate 140:	0.3 mm.
18	Fifth simple plate 150:	0.3 mm.
19	Sixth simple plate 160:	0.3 mm.
20	Seventh simple plate 170:	0.2 mm.
21	Eighth simple plate 180:	0.3 mm.
22	Ninth simple plate 190:	0.6 mm.
23	Tenth simple plate 200:	0.3 mm.
24	Eleventh simple plate 210:	0.2 mm.
25	Twelfth simple plate 220:	0.3 mm.
26	Thirteenth simple plate 230:	0.6 mm.
27	Fourteenth simple plate 240:	0.3 mm.
28	Fifteenth simple plate 250:	0.3 mm.
29	Sixteenth simple plate 260:	3.0 mm.

30 Simple plates 110 and 260 (the top and bottom simple plates) are thicker than other plates to
provide greater structural stability. Simple plates 120-160, 200, 220, 240 and 250 are much thinner,
to enhance heat transfer. As will be discussed below, a thickness of 0.3 mm provides a reasonable
heat transfer ability for a wide variety of materials.

For simple plates that include solid portions used to transfer thermal energy to or from heat
exchangers, a preferred thickness is about 0.3 mm. As plate thickness increases, mechanical stability
increases and heat transfer ability decreases. The 0.3 mm thickness provides good heat transfer

1 characteristics without sacrificing mechanical stability. When graphs representing mechanical
2 stability as a function of plate thickness (50µm-1 mm) and heat transfer ability as a function of plate
3 thickness (50µm-1 mm) are combined, the curves representing each functional relationship intersect
4 at approximately 0.3 mm. It should be noted that this optimum value of 0.3 mm is independent of the
5 actual material selected (glass, metal, plastic, etc.). While the shape of the curves defining the
6 functional relationships change when a different material is selected, the intersection of the curves at
7 0.3 mm remains relatively constant. Thus, 0.3 mm represents a simple plate thickness that provides
8 for reasonable heat transfer ability without sacrificing structural integrity.

9 FIGURE 17A illustrates a fluid flow path of Reactant A, as it enters top simple plate 110 and
10 proceeds through the sixth simple plate 160 of reactor 100. Reactant A enters through an inlet 115 in
11 top simple plate 10, proceeds to second simple plate 120 of the second layer, and enters a Reactant A
12 distributor 125. Reactant A then passes to third simple plate 130 of the third layer, passing through
13 four Reactant A openings 135. In fourth simple plate 140 of the fourth layer, Reactant A passes
14 through four Reactant A openings 145, which are part of an inter-digital-mixer, whose purpose is to
15 precisely align the fluid flows for Reactants A and B to optimize mixing in later layers of the reactor.
16 The purpose of Reactant A openings 145 is to precisely align a plurality of Reactant A fluid paths
17 with a plurality of Reactant B fluid paths, so that a stacked laminar flow can be achieved with
18 equilibrated pressure drops. It should be noted that a first heat exchanger 124 (see FIGURE 17A) is
19 used to bring both Reactants A and B to the proper temperature in the inter-digital-mixer of the fourth
20 layer.

21 In the fifth layer, fifth simple plate 150 incorporates a plurality of reactant A openings 155
22 that are aligned with a plurality of Reactant B openings 157 (see FIGURE 17B). These openings
23 form an alternating pattern of 24 openings in four rows of six openings each (for a total of 12
24 Reactant A openings and 12 Reactant B openings). In the sixth layer, sixth simple plate 160
25 incorporates four fluid channels 165. It is in the four channels 165 that Reactants A and B first
26 intermingle. Because of the pattern of fluid paths for Reactants A and B enabled by the inter-digital-
27 mixer, Reactants A and B enter channels 165 in a stacked laminar flow pattern.

28 FIGURE 17B illustrates the fluid path that Reactant B takes in entering the first six layers of a
29 reactor 100. Reactant B enters top simple plate 110 through opening 117, passes through the second
30 layer an identical Reactant B openings 117 in second simple plate 120. In the third layer, Reactant B

1 enters Reactant B distributor 137 in third simple plate 130. In the fourth layer, Reactant B enters four
2 Reactant B openings 147 in fourth simple plate 140. Openings 147 and 145 are collectively referred
3 to as the inter-digital-mixer. After passing through the fourth layer, Reactant B flows into twelve
4 openings 157 in fifth simple plate 150, of the fifth layer. Reactant B then proceeds to the four fluid
5 channels 165 on sixth simple plate 160, where Reactants A and B are first co-mingled.

6 FIGURE 17C illustrates the combined flows of Reactants A and B after passing through the
7 sixth layer and proceeding through layers 7-16 of reactor 100. Reactants A and B as combined (in a
8 stacked laminar flow pattern) flow through four fluid channels 175 on seventh simple plate 170.
9 Channels 175 lead to four mixing chambers 177. In mixing chambers 177, the stacked laminar flow
10 is compressed, further enhancing rapid diffusion mixing. A second heat exchanger 146 (see
11 FIGURE 18B) is used to control the temperature of the reactants as they mix in mixing
12 chambers 177. After Reactants A and B become thoroughly mixed in mixing chambers 177, the now
13 mixed Reactants A and B flow through a plurality of mixed reactant openings 185 on eighth simple
14 plate 180. The mixed reactants then flow through the ninth and tenth layers via identical mixed
15 reactant openings 185 in simple plates 190 and 200, respectively. The mixed reactants then flow into
16 reaction channels 116 on eleventh simple plate 210. Reaction channels 116 preferably provide
17 sufficient residence time so that the majority (if not all) of the reaction is complete. If reaction
18 channels 116 do not provide sufficient residence time, then an additional residence time chamber can
19 be added downstream of reactor 100. As noted above, the quality and yield of the desired reaction is
20 greatly affected by the ability to control temperature during the reaction process. The preferred
21 reactor provides heat exchangers on simple plates 190 and 230 to precisely control the temperature
22 within reaction channels 116. If additional residence time chambers are required, then control of the
23 temperature in the additional residence time chambers is also highly desirable. After passing through
24 reaction channels 116 in the eleventh layer, the resulting product passes through a plurality of product
25 openings 126 in simple plates 220, 230, and 240 of layers 12, 13 and 14, respectively. The eight
26 individual product streams represented by these product openings are then combined into a single
27 product channel 156 on fifteenth simple plate 250, of layer 15. This single product exits the reactor
28 via a product outlet 167 on sixteenth simple plate 260, in the bottom (sixteenth) layer of the reactor.

29 FIGURES 18A-18C illustrate the fluid paths for heat transfer media A, B, and C throughout
30 the preferred reactor. FIGURE 18A illustrates the fluid path for heat transfer media B, which

1 services first heat exchanger 124 in the second layer. Heat transfer media B flows into heat transfer
2 media inlet 114a in top simple plate 110 and proceeds to heat exchanger 124 on second simple
3 plate 120. Heat transfer media B passes through heat exchanger 124, and exits heat exchanger 124
4 via outlet port 114b in top simple plate 110. The purpose of heat exchanger 124 is to adjust the
5 temperature of the solid section of portion of the third layer that is immediately above the inter-
6 digital-mixer (openings 145 and 147) in fourth simple plate 140. In this manner, heat exchanger 124
7 is moderating the temperatures of Reactants A and B prior to the reactants being mixed together. It is
8 contemplated that for the majority of reactions, it will be desirable for Reactants A and B to be of
9 similar temperature. Those of ordinary skill in the art will readily understand, however, that there
10 may be some reactions in which Reactant A and Reactant B will preferably be kept at separate
11 temperatures. It is contemplated that a different stacked plate design using the same principles of the
12 invention can be designed and fabricated to provide for a separate heat exchanger to individually
13 modify the temperatures of Reactants A and B.

14 FIGURE 18B illustrates the fluid path that heat transfer media C takes through layers 1-4 of
15 the preferred reactor. Heat transfer media C enters the reactor through inlet 116a in top simple
16 plate 110 and then proceeds through heat transfer media C intake manifolds 126a on simple
17 plates 120 and 130, in layers 2 and 3, respectively. Heat transfer media C then enters heat
18 exchanger 146 on fourth simple plate 140 of layer 4 and exits heat exchanger 146 by utilizing heat
19 transfer media C exhaust manifolds 126b of simple plates 130 and 120, in layers 3 and 2,
20 respectively. Heat transfer media C then exits the reactor using outlet port 116b of top simple
21 plate 110. The purpose of second heat exchanger 146 is to modify the temperature of the solid
22 portion of sixth simple plate 160 that corresponds to the mixing chambers 177 of seventh simple
23 plate 170. Because the mixing of chemicals often spontaneously generates heat, a great deal of heat
24 can be generated as Reactants A and B are thoroughly mixed. Second heat exchanger 146 is thus
25 able to cool Reactants A and B while in mixing chambers 177, so that the temperatures of the
26 reactants do not exceed the ideal temperature for the desired reaction. Second heat exchanger 146
27 occupies both the fourth and fifth layers (simple plates 140 and 150), to increase the capacity of the
28 heat exchanger.

29 FIGURE 18C illustrates the fluid path for heat transfer media A as it passes through the first
30 thirteen layers of preferred reactor 100. Heat transfer media A enters the reactor at top simple

1 plate 110 via intake port 112a. The heat transfer media A then passes through identical heat transfer
2 media A intake manifolds 122a on simple plates 120 and 130 of layers 2 and 3 respectively. Heat
3 transfer media A continues to pass through heat transfer media A intake manifolds in layers 4, 5, 6
4 and 7, via intake manifolds 142a. It should be noted that intake manifolds 142a differ in size and
5 shape relative to the intake manifolds 122a of layers 2 and 3. The functional purpose of the size
6 change is both reduce potential pressure drops within the fluid paths of the reactor, as well as to
7 reduce the surface area of simple plates 140-170 to enhance bonding.

8 In layer 8, the shape of heat transfer media A intake manifold 182a changes once again. The
9 purpose of the size change between the heat transfer media A intake manifolds in layers 7 and 8 is so
10 that heat transfer media A can be fed into two separate sections of the layer 9. In a first heat transfer
11 media A fluid path in layer 9, heat transfer media A flows into a heat transfer media A intake
12 manifold 142a, and from there to heat transfer media A intake manifold 42a of tenth simple plate 200
13 in layer 10. From there, heat transfer media A flows to heat transfer media A intake manifold 142a in
14 layer 11, an enlarged heat transfer media A intake manifold in layer 12, and then to heat transfer
15 media A intake manifold 142a in layer 13.

16 In a second heat transfer media A fluid path in layer 9, fluid flows out of heat transfer
17 media A intake manifold 182a of eighth simple plate 180 and into third heat exchanger 193 on ninth
18 simple plate 190 of layer 9. The purpose of third heat exchanger 193 is to moderate the temperature
19 of the solid portion of layer 10 immediately adjacent to reaction channels 116 in layer 11. Heat
20 transfer media A exits heat exchanger 193 by returning to layer 8 via heat transfer media A exhaust
21 manifold 182a, which is enlarged and overlaps the right end of third heat exchanger 193.

22 Simple plate 200 of layer 10 includes enlarged heat transfer media A intake manifold 182a (as
23 well as exhaust manifold 182b). It should be noted that reaction channels 116 of layer 11 are not
24 quite long enough to overlap the enlarged heat transfer medial intake and exhaust manifolds 182a and
25 182b, thus no heat transfer media enters reaction channels 116. Here, the functional purpose of the
26 size change of the intake and exhaust manifolds is to reduce the surface area of tenth simple
27 plate 200, to enhance bonding, rather than to feed a heat exchanger (as in layer 8 and eighth simple
28 plate 180).

29 Referring now to layer 11, note that again the size and shape of heat transfer media A intake
30 manifold 142a has changed relative to the intake manifolds of layers 8 and 10. This size change

1 relates to maintaining a calculated fluidic equilibrium throughout the micro reactor. However, it is
2 contemplated that the overall effect of the size change is relatively minor, and that an effective micro
3 reactor can be achieved without changing the size of the intake manifolds on layer 11.

4 In layer 12, the size and shape of heat transfer media A intake manifold 182a is again
5 enlarged, to once again divert some heat transfer fluid A into a second fluid path that services fourth
6 heat exchangers 133a and 133b of layer 13. Heat transfer media A also flows into a heat transfer
7 media A intake manifold 42a in layer 13. The functional purpose of heat transfer media A intake
8 manifold 142a of layer 13 is to ensure that the fluid pressure within fourth heat exchangers 133a
9 and 133b matches the fluid pressure within third heat exchanger 193. Note both the third and fourth
10 heat exchangers are moderating the temperature of reaction channels 116, and thus preferably both
11 heat exchanges should have similar flow characteristics.

12 Heat transfer fluid A that has entered fourth heat exchangers 133a and 133b exits layer 13 via
13 heat transfer media A exhaust manifold 142b in layer 12. From there, heat transfer media A moves
14 successively through heat transfer media exhaust manifolds 142b in layer 11, 182b in layer 10,
15 142b in layer 9, 182b in layer 8, 142b in layers 7-4 and 122b in layers 3-2. Heat transfer media A
16 finally exits the reactor via outlet 112b in top simple plate 110.

17 Generally the heat transfer media used in the preferred reactor will be liquids, although it is
18 envisioned that selected gases may also be beneficially employed. Fluidized solid heat transfer media
19 (such as sand or silica) are known in the art, and might be used, though the dimensions involved in
20 the fluid channels of the preferred reactor raise the concern that the solid heat transfer media could
21 cause clogging of the heat transfer pathways.